

# NITRATE/NITRITE

## FACT SHEET



See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cost Assumptions; Raw Water Composition; Total Plant Costs; and WaTER Program.

### 1. CONTAMINANT DATA

**A. Chemical Data:** Nitrate ( $\text{NO}_3^-$ ) and Nitrite ( $\text{NO}_2^-$ ) are inorganic anions.  $\text{NO}_3^-$  has an oxidation state of elemental nitrogen gas, molecular weight 62.00.  $\text{NO}_3^-/\text{NO}_2^-$  are water-soluble, colorless, odorless, and tasteless.  $\text{NO}_3^-$  is a macro-nutrient that is an essential part of proteins manufactured by bacteria and algae in water.  $\text{NO}_2^-$  is a nitrogen-oxygen radical.

**B. Source in Nature:** Nitrogen is a naturally occurring gas in the earth's atmosphere, at approximately 78% by volume.  $\text{NO}_3^-$  are naturally occurring nitrogen-oxygen units which combine with various organic and inorganic compounds in both water and plants. Natural sources of  $\text{NO}_3^-$  in waters include direct fixation of nitrogen gas by algae and bacteria, photochemical fixation, electrical discharge, and oxidation of ammonia and nitrite by nitrifying bacteria.  $\text{NO}_3^-$  are used by bacteria to form amino acids used in the synthesis of proteins for all plants and animals. Elevated levels of  $\text{NO}_3^-$  in today's surface and groundwaters are a result of overuse of nutrient-rich chemical fertilizers, municipal and industrial wastewaters, refuse dumps, and improper disposal of human and animal wastes. Both  $\text{NO}_3^-$  and  $\text{NO}_2^-$  are added to meat products as preservatives.  $\text{NO}_3^-$  are reduced to  $\text{NO}_2^-$  in the saliva of the mouth and upper GI tract.

**C. SDWA Limits:** MCL for  $\text{NO}_3^-$  as nitrogen is 10 mg/L (for  $\text{NO}_3^-$  as Nitrate, the MCL is 45 mg/L). MCL/MCLG for  $\text{NO}_2^-$  is 1 mg/L.

**D. Health Effects of Contamination:** The health effects of excessive  $\text{NO}_3^-/\text{NO}_2^-$  include Methemoglobinemia (blue baby syndrome - oxygen deprivation in infants under 6 months), and is generally considered a concern for children under age 5. Older children and adults are generally only susceptible if they also experience enzyme or erythrocyte metabolism deficiency, chronic anemia, or gastric diseases.

### 2. REMOVAL TECHNIQUES

**A. USEPA BAT:** Ion exchange, reverse osmosis, or electrodialysis.

! IX uses charged anion resin to exchange acceptable ions from the resin for undesirable  $\text{NO}_3^-$  in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; competing ions.

! RO uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids, to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.

! EDR uses semipermeable membranes in which ions migrate through the membrane from a less concentrated to a more concentrated solution as a result of the ions' representative attractions to direct electric current. Benefits: contaminant specific removal. Limitations: electrical requirements; concentrate disposal.

**B. Alternative Methods of Treatment:** Biological denitrification or chemical reduction; distillation; dilution by blending with higher quality water; or water source relocation. Note: Boiling water concentrates nitrates.

#### **C. Related WTP Publications:**

- 1) WTP Report #14, "Brighton ED Testing with Asahi Monovalent Selective Membranes." This report summarizes the pilot testing of an ED water treatment system with special membranes tailored for nitrate removal from water.
- 2) WTP Report #15, "Maricopa Groundwater Treatment Study." This report summarizes the field study performed to determine the suitability of several water treatment processes, including RO, ED, and NF, on groundwater containing high levels of nitrate, chloride, and TDS; recommends the use of NF or ED for study area.

**D. Safety and Health Requirements for Treatment Processes:** Personnel involved with demineralization treatment processes should be aware of the chemicals being used (MSDS information), the electrical shock hazards, and the hydraulic pressures required to operate the equipment. General industry safety, health, and self protection practices should be followed, including proper use of tools.

### 3. BAT PROCESS DESCRIPTION AND COST DATA

**General Assumptions:** Refer to: Raw Water Composition Fact Sheet for ionic concentrations; and Cost Assumptions Fact Sheet for cost index data and process assumptions. All costs are based on ENR, PPI, and BLS cost indices for March 2001. General sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal are not included.

### 3A. Ion Exchange:

**Process** - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. Anion IX is a reversible chemical process in which ions from an insoluble, permanent, solid resin bed are exchanged for ions in water. The process relies on the fact that water solutions must be electrically neutral, therefore ions in the resin bed are exchanged with ions of similar charge in the water. As a result of the exchange process, no reduction in ions is obtained. In the case of  $\text{NO}_3^-/\text{NO}_2^-$ , operation begins with a fully recharged resin bed, having enough  $\text{Cl}^-$  or  $\text{OH}^-$  ions to carry out the anion exchange. Usually polymer resin bed is composed of millions of medium sand grain size, spherical beads. As water passes through the resin bed, the  $\text{Cl}^-$  or  $\text{OH}^-$  anions are released into the water, being substituted or replaced with  $\text{NO}_3^-/\text{NO}_2^-$  anions (ion exchange). When the resin becomes exhausted of  $\text{Cl}^-$  or  $\text{OH}^-$  ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the  $\text{NO}_3^-/\text{NO}_2^-$  ions with  $\text{Cl}^-$  ions. Current resins are not completely  $\text{NO}_3^-/\text{NO}_2^-$  selective and may remove other anions, such as  $\text{SO}_4^{2-}$ , before removing the nitrate compounds. Therefore,  $\text{NO}_3^-/\text{NO}_2^-$  ion exchange requires careful consideration of the complete raw water characteristics. Typically,  $\text{NO}_3^-/\text{NO}_2^-$  ion exchange utilizes a  $\text{Cl}^-$  or  $\text{OH}^-$ , strongly basic anion resin bed.

**Pretreatment** - Guidelines are available on accepted limits for pH, organics, turbidity, and other raw water characteristics. Pretreatment may be required to reduce excessive amounts of TSS which could plug the resin bed, and typically includes media or carbon filtration.

**Maintenance** - Depending on raw water characteristics and  $\text{NO}_3^-/\text{NO}_2^-$  concentration, the resin will require regular regeneration with a NaCl solution. Preparation of the NaCl solution is required. Frequent monitoring is required to ensure nitrate removal. If utilized, filter replacement and backwashing will be required.

**Waste Disposal** - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated  $\text{NO}_3^-/\text{NO}_2^-$  solution); occasional solid wastes (in the form of broken resin beads) which are backwashed during regeneration; and if utilized, spent filters and backwash waste water.

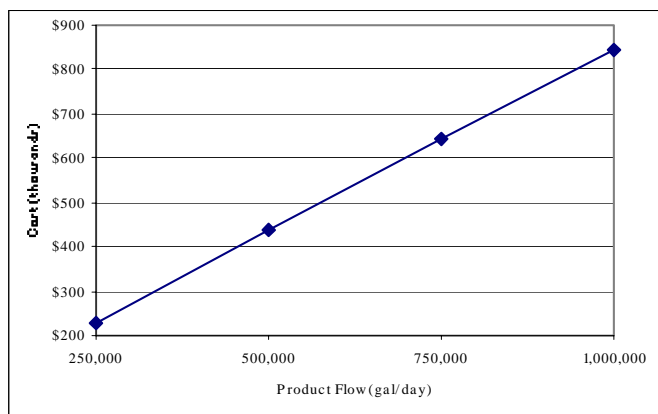
#### Advantages -

- ! Ease of operation; highly reliable.
- ! Lower initial cost; resins will not wear out with regular regeneration.
- ! Effective; widely used.
- ! Suitable for small and large installations.

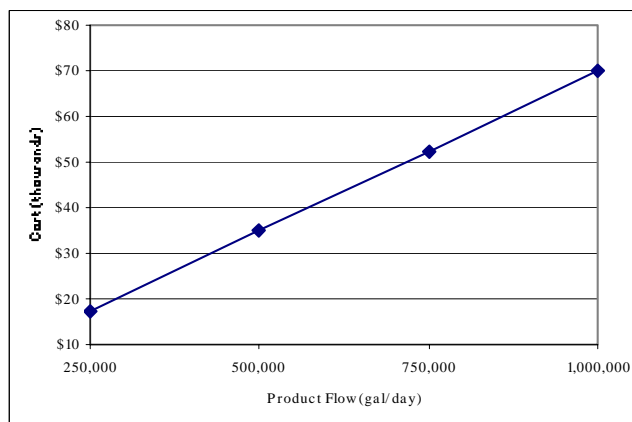
#### Disadvantages -

- ! Does not completely eliminate all  $\text{NO}_3^-/\text{NO}_2^-$ .
- ! Requires frequent monitoring for nitrate removal.
- ! Requires salt storage.
- ! Strongly basic anion resins are susceptible to organic fouling; reduced life; thermodynamically unstable.

**BAT Equipment Cost\***



**BAT Annual O&M Cost\***



\*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

### 3B. Reverse Osmosis:

**Process** - RO is a physical process in which contaminants are removed by applying pressure on the feed water to direct it through a semipermeable membrane. The process is the "reverse" of natural osmosis (water diffusion from dilute to concentrated through a semipermeable membrane to equalize ion concentration) as a result of the applied pressure to the concentrated side of the membrane, which overcomes the natural osmotic pressure. RO membranes reject ions based on size and electrical charge. The raw water is typically called feed; the product water is called permeate; and the concentrated reject is called concentrate. Common RO membrane materials include asymmetric cellulose acetate or polyamide thin film composite. Common membrane construction includes spiral wound or hollow fine fiber. Each material and construction method has specific benefits and limitations depending upon the raw water characteristics and pretreatment. A typical large RO installation includes a high pressure feed pump, parallel 1st and 2nd stage membrane elements (in pressure vessels); valving; and feed, permeate, and concentrate piping. All materials and construction methods require regular maintenance. Factors influencing membrane selection are cost, recovery, rejection, raw water characteristics, and pretreatment. Factors influencing performance are raw water characteristics, pressure, temperature, and regular monitoring and maintenance.

**Pretreatment** - RO requires a careful review of raw water characteristics and pretreatment needs to prevent membranes from fouling, scaling, or other membrane degradation. Removal of suspended solids is necessary to prevent colloidal and bio-fouling, and removal of dissolved solids is necessary to prevent scaling and chemical attack. Large installation pretreatment can include media filters to remove suspended particles; ion exchange softening or antiscalant to remove hardness; temperature and pH adjustment to maintain efficiency; acid to prevent scaling and membrane damage; activated carbon or bisulfite to remove chlorine (postdisinfection may be required); and cartridge (micro) filters to remove some dissolved particles and any remaining suspended particles.

**Maintenance** - Monitor rejection percentage to ensure  $\text{NO}_3^-/\text{NO}_2^-$  removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly flushed through the system at high volume/low pressure with a cleaning agent to remove fouling and scaling. The system is flushed and returned to service.  $\text{NaHSO}_3$  is a typical caustic cleaner. RO stages are cleaned sequentially. Frequency of membrane replacement dependent on raw water characteristics, pretreatment, and maintenance.

**Waste Disposal** - Pretreatment waste streams, concentrate flows, and spent filters and membrane elements all require approved disposal.

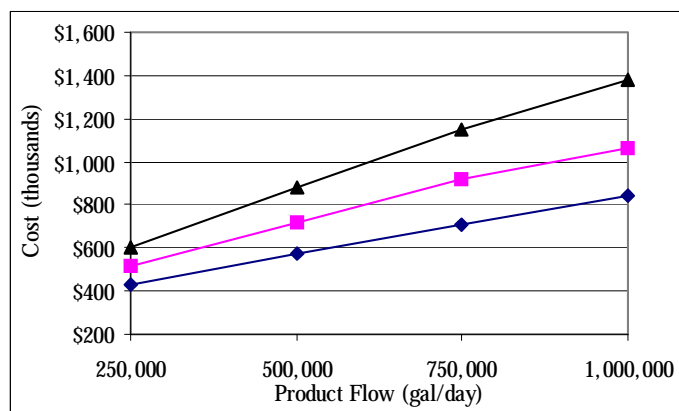
#### Advantages -

- ! Produces highest water quality.
- ! Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- ! Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

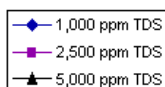
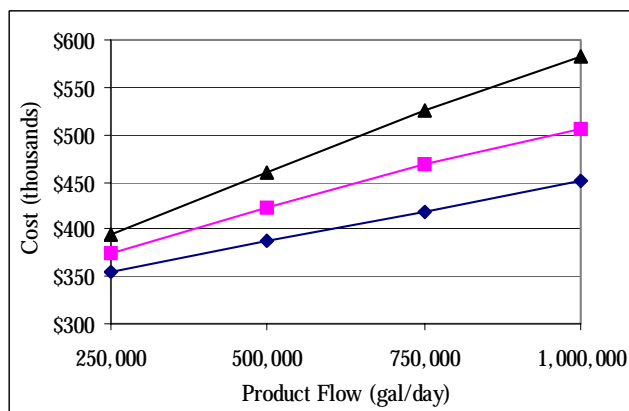
#### Disadvantages -

- ! Relatively expensive to install and operate.
- ! Frequent membrane monitoring and maintenance; monitoring of rejection percentage for  $\text{NO}_3^-/\text{NO}_2^-$  removal.
- ! Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

**BAT Equipment Cost\***



**BAT Annual O&M Cost\***



\*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

### 3C. Electrodialysis Reversal:

**Process** - EDR is an electrochemical process in which ions migrate through an ion-selective semipermeable membrane as a result of their attraction to the electrically charged membrane surface. A positive electrode (cathode) and a negative electrode (anode) are used to charge the membrane surfaces and to separate contaminant molecules into ions. The process relies on the fact that electrical charges are attracted to opposite poles. As a result of the removal process, reduction in ions (or TDS) is obtained. A common EDR system includes a membrane stack which layers several cell pairs, each consisting of a cation transfer membrane, a demineralized flow spacer, an anion transfer membrane, and a concentrate flow spacer. Electrode compartments are at opposite ends of the stack. The influent feed water (chemically treated to prevent precipitation) and concentrated reject flow in parallel across the membranes and through the demineralized and concentrate flow spacers, respectively. The electrodes are continually flushed to prevent fouling or scaling. Careful consideration of flush feed water is required. Typically, the membranes are cation- or anion-exchange resins cast in sheet form; the spacers are HDPE; and the electrodes are inert metal. EDR stacks are tank contained and often staged. Membrane selection is based on careful review of raw water characteristics. A single-stage EDR system usually removes 50 percent of the TDS; therefore, for water with more than 1000 mg/L TDS, blending with higher quality water or a second stage is required to meet 500 mg/L TDS. EDR uses the technique of regularly reversing the polarity of the electrodes, thereby freeing accumulated ions for cleaning. This process requires additional plumbing and electrical controls, but increases membrane life, does not require added chemicals, and eases cleaning.

**Pretreatment** - Guidelines are available on accepted limits on pH, organics, turbidity, and other raw water characteristics. Typically requires chemical feed to prevent scaling, acid addition for pH adjustment, and a cartridge filter for prefiltration.

**Maintenance** - EDR membranes are durable, can tolerate pH from 1 - 10, and temperatures to 115°F for cleaning. They can be removed from the unit and scrubbed. Solids can be washed off by turning the power off and letting water circulate through the stack. Electrode washes flush out byproducts of electrode reaction. The byproducts are hydrogen, formed in the cathode spacer, and oxygen and chlorine gas, formed in the anode spacer. If the chlorine is not removed, toxic chlorine gas may form. Depending on raw water characteristics and  $\text{NO}_3^-/\text{NO}_2^-$  concentration, the membranes will require regular maintenance or replacement. EDR requires system flushes at high volume/low pressure; EDR backwashing will be required.

**Waste Disposal** - Highly concentrated reject flows, electrode cleaning flows, and spent membranes require approved disposal. Pretreatment processes and spent materials also require approved disposal.

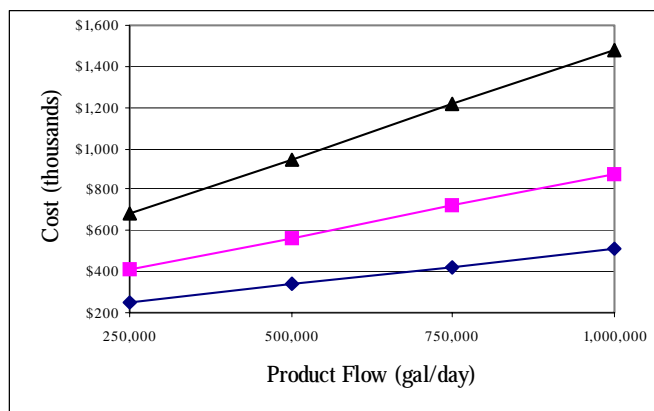
#### Advantages -

- ! EDR can operate without fouling or scaling, or chemical addition; suitable for higher TDS sources.
- ! Low pressure requirements; typically quieter than RO.
- ! Long membrane life expectancy; EDR extends membrane life and reduces maintenance.

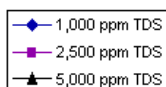
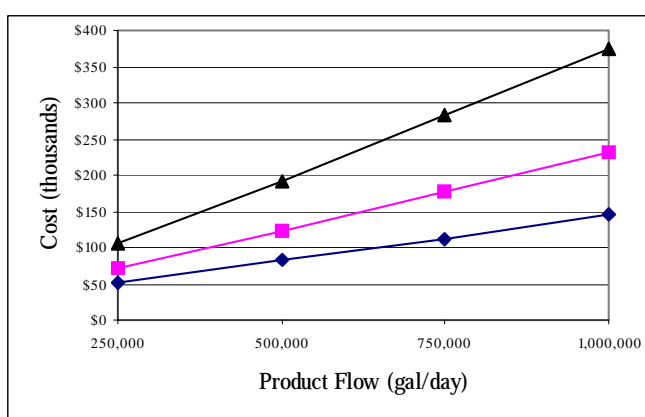
#### Disadvantages -

- ! EDR can operate without fouling or scaling, or chemical addition; suitable for higher TDS sources.
- ! Not suitable for high levels of Fe and Mn,  $\text{H}_2\text{S}$ , chlorine, or hardness.
- ! Limited current density; current leakage; back diffusion.
- ! At 50% rejection of TDS per pass, process is limited to water with 3000 mg/L TDS or less.

**BAT Equipment Cost\***



**BAT Annual O&M Cost\***



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